1st TALK

- **MULTISPECTRAL MICROSCOPY**
  CAMEVA SYSTEM

2nd TALK

- **AUTOMATED CHARACTERISATION OF INTERGROWTH TEXTURES IN MINERAL PARTICLES**
  A CASE STUDY

Laura **PÉREZ-BARNUEVO**

laura.perez.barnuevo@upm.es

POLITÉCNICA

"Ingeniamos el futuro"

Aitemin
Centro Tecnológico

MULTISPECTRAL MICROSCOPY

CAMEVA SYSTEM

Université de Liège

RUB

Introduction

CAMEVA SYSTEM

Automated optical identification of ore minerals in polished samples using multispectral digital images

- Mineralogy
  - » Support for basic ore microscopy / ore identification
- Geometallurgy
  - » Automated system for quantitative mineralogy applications, more efficient than manual methods and less expensive than SEM systems.

THE CONSORTIUM

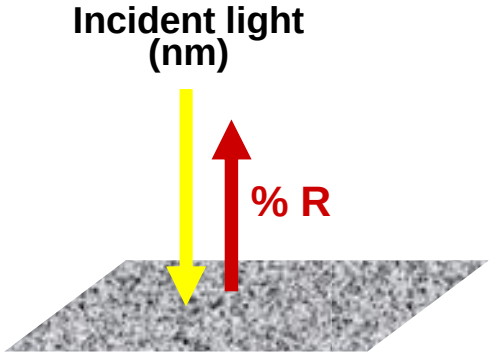
- Universidad Politécnica de Madrid, Spain
- AITEMíN, Spain
- Université de Liège, Belgium
- Ruhr-Universität Bochum, Germany

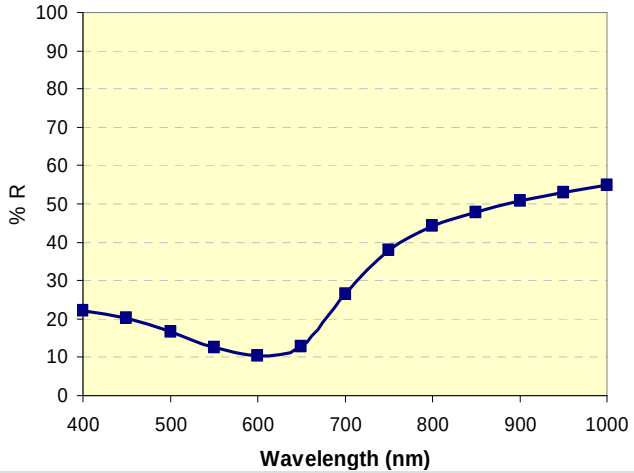
Ore microscopy is an assential tool for geologists and mineralogists

USUAL OBSERVED MINERAL PROPERTIES

- » Colour
- » Reflectance
- » Relief
- » Anisotropy
- » Internal reflections
- » Birreflectance
- » Etc.

REFLECTANCE

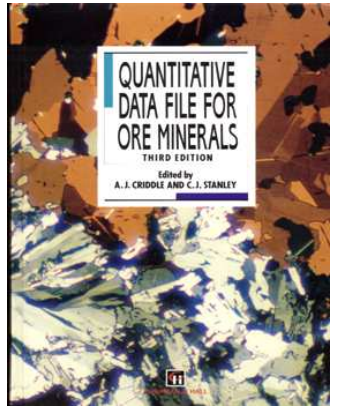




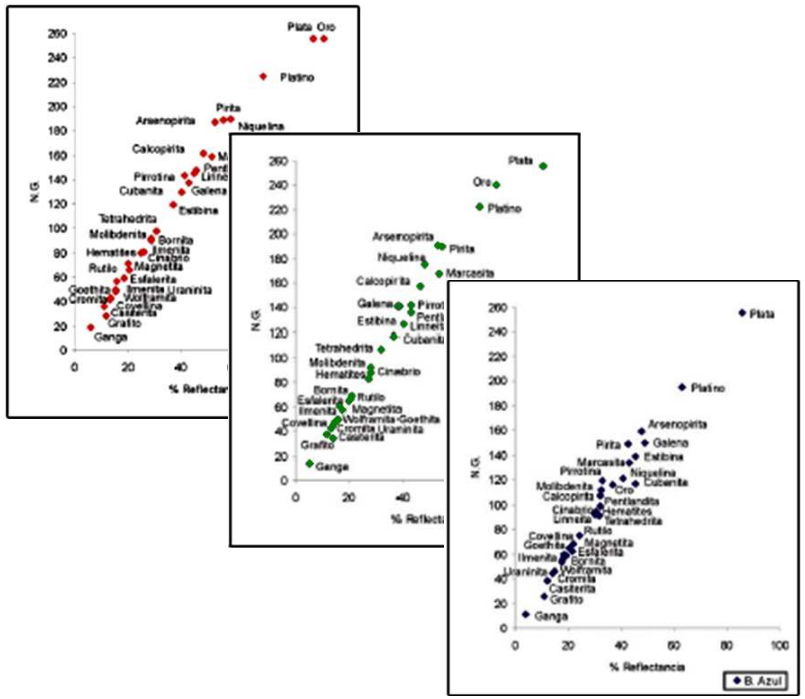
- **Background**

  – **QDF3** (Criddle A. & Stanley Ch., 1993)

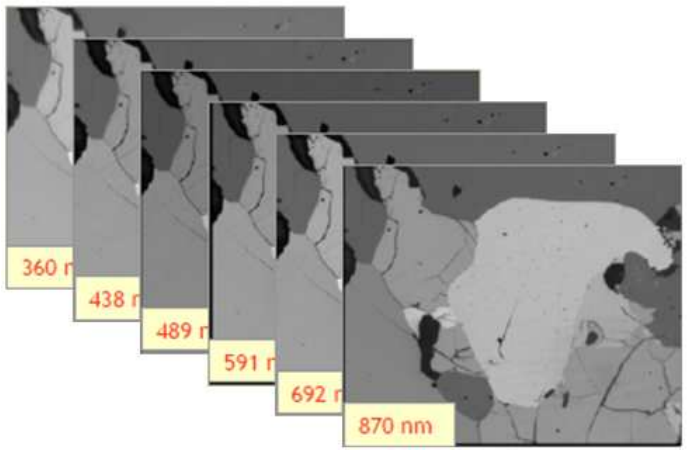
    - Reflectance spectrum data base from **400 nm** to **700 nm**



  – **RGB Imaging** (Berrezueta E., 2004)

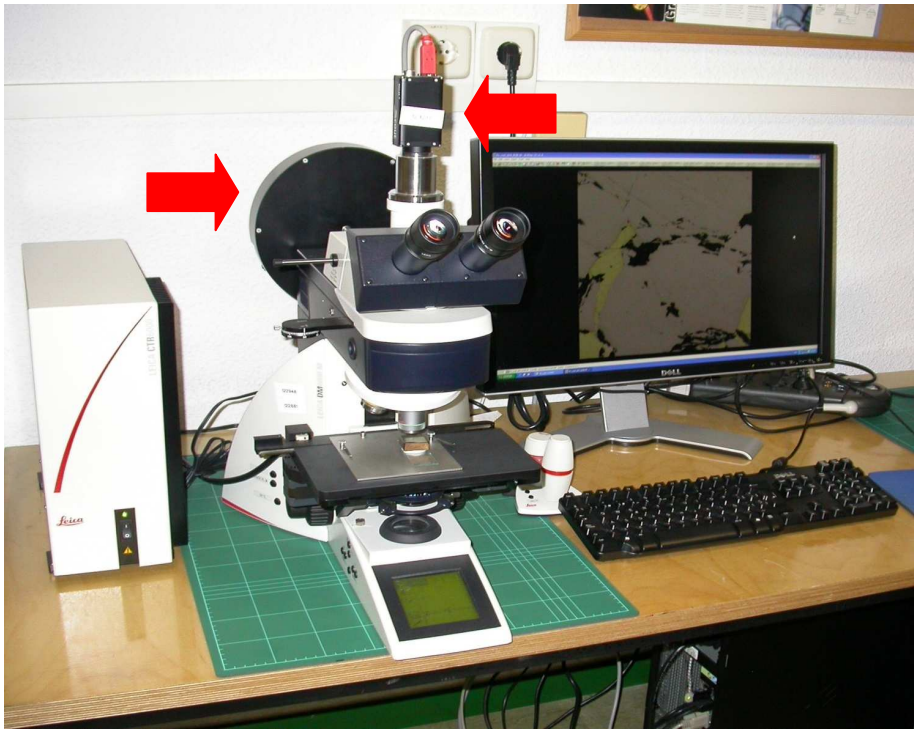


  – **Multispectral Imaging principles** (Pirard E., 2004)



Instrumentation

- **EQUIPMENT**
  - ✓ **Automated reflected light microscope**
  - ✓ **W/B digital video camera**
  - ✓ **Rotating filter wheel**
    - **13 Interference filters from 400 to 1000 nm, in 50 nm intervals**
  - ✓ **Reflectance Standards**

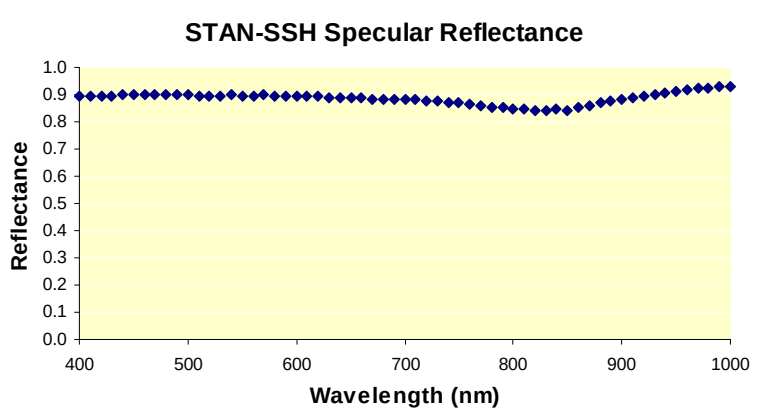


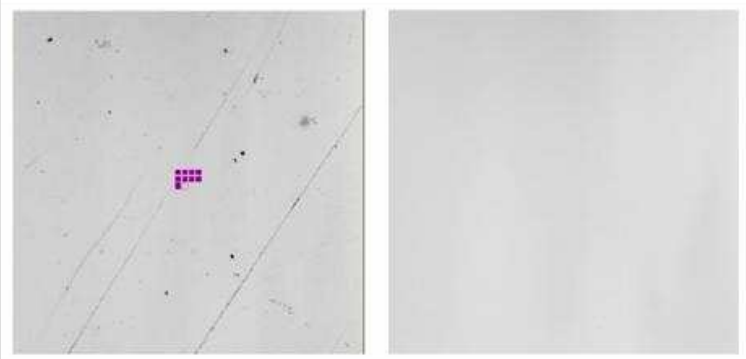
Experimental process

- Calibration
- Image acquisition
- Data base construction
- Mineral identification software

EXPERIMENTAL PROCESS

- **Calibration**
  - Stabilized illumination
  - Integration timing adjusted for each filter
    - Grey level output matches with reflectance values
  - Focusing distance adjusted for each filter and each objective
    - Optimun focusing
  - Background correction
    - Grey level uniform throughout scene



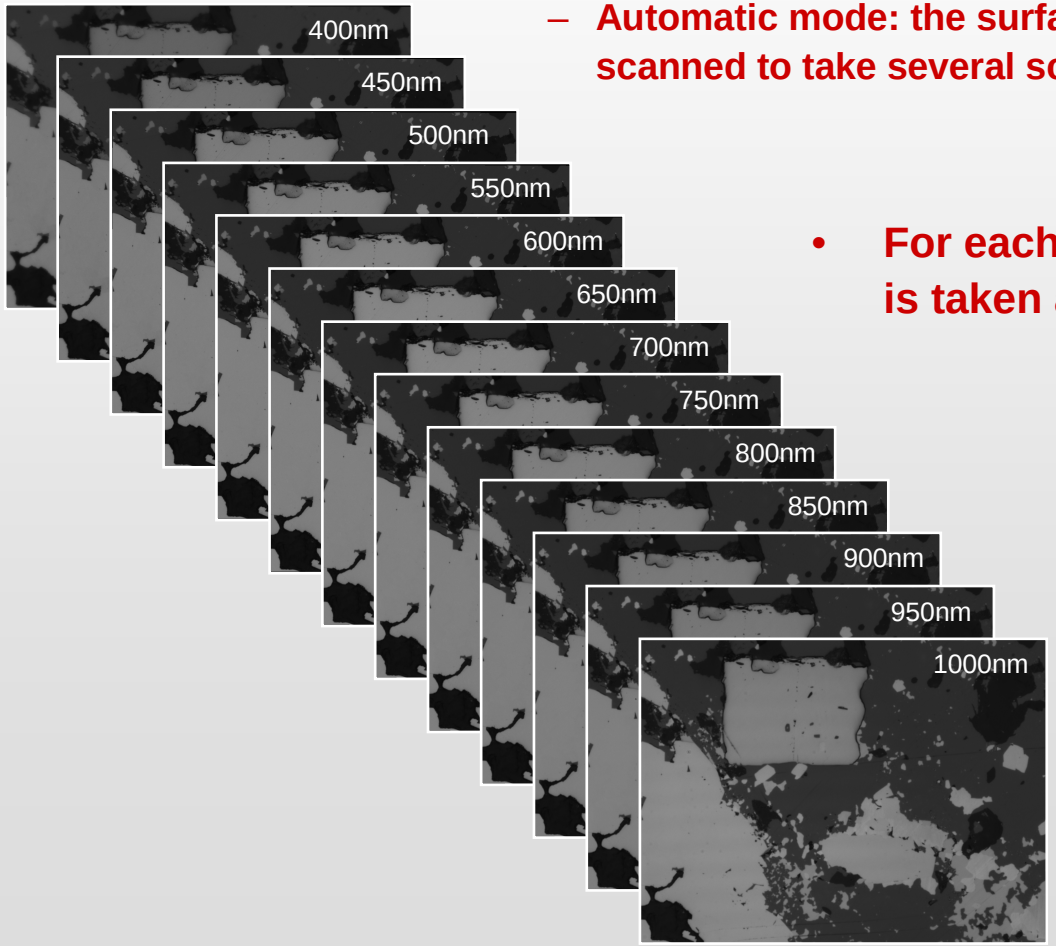


EXPERIMENTAL PROCESS

- **Image acquisition**

The system can operate in

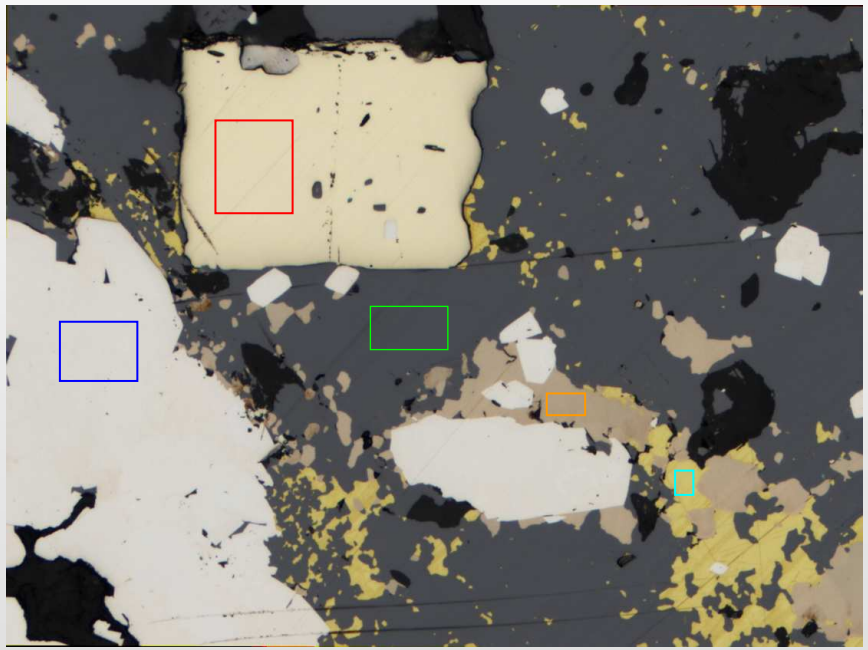
- **Manual mode: just one scene is taken**
- **Automatic mode: the surface of the polished sample is scanned to take several scenes**



- **For each scene a package of 13 images is taken and stored**

EXPERIMENTAL PROCESS

- **Data Base construction**

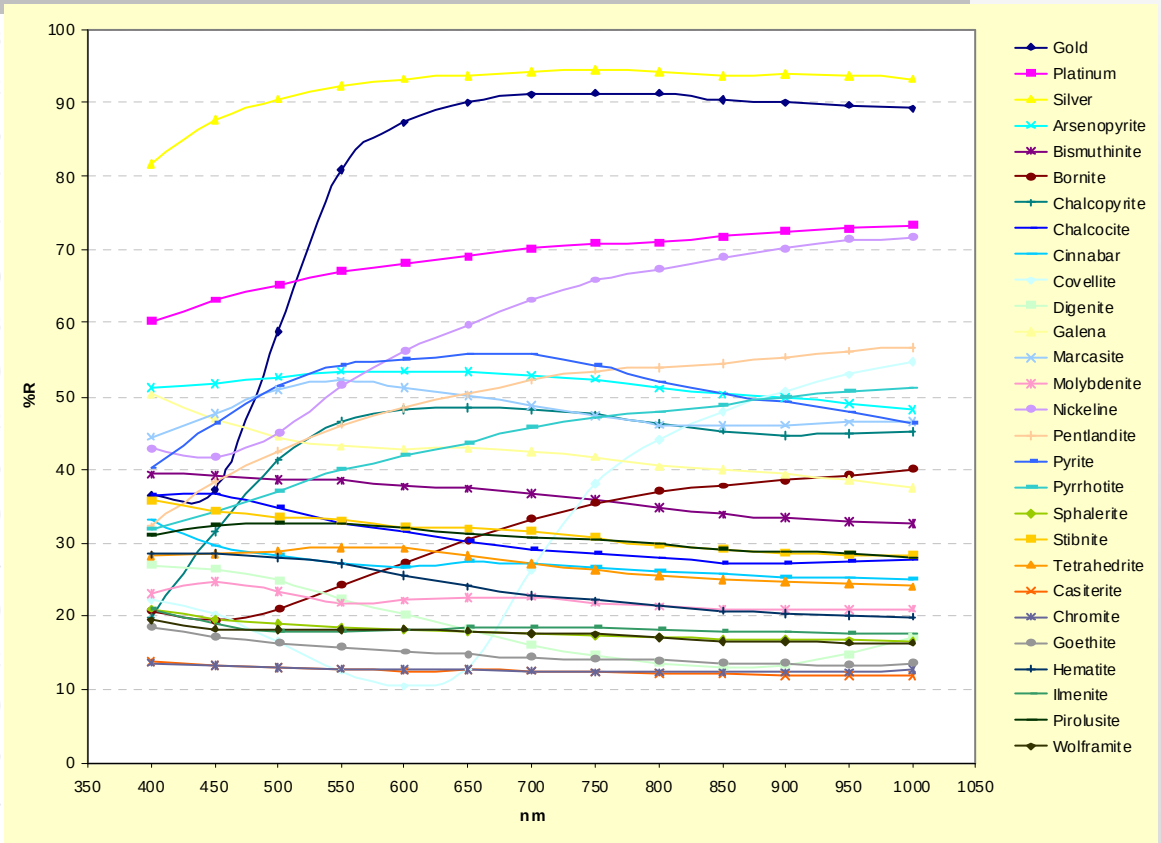


- **Representative samples with important minerals were selected.**
- **For each mineral multispectral images were taken**
- **Regions of interest (ROI) for each mineral were selected and multispectral reflectance data extracted and stored.**

EXPERIMENTAL PROCESS

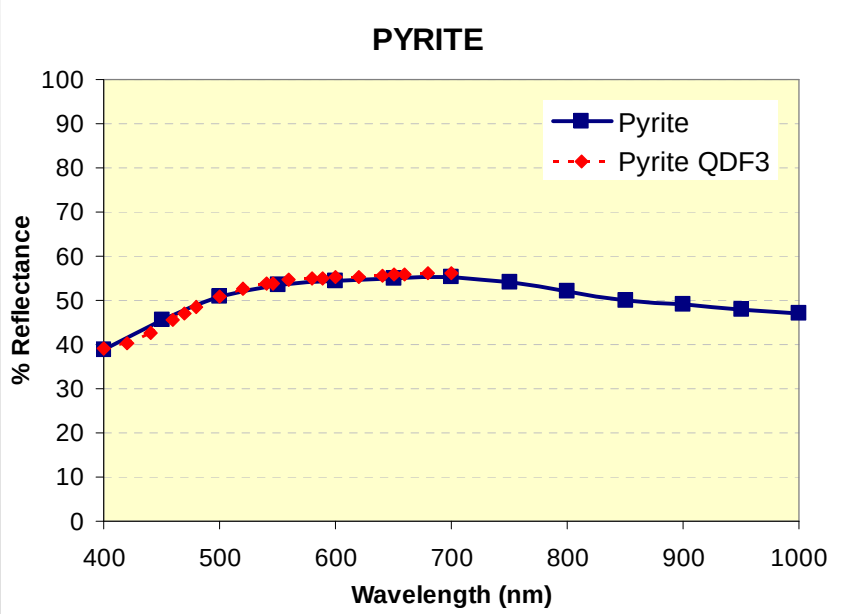
- **Data base construction**
  - **A Data Base containing multispectral reflectance values was created.**

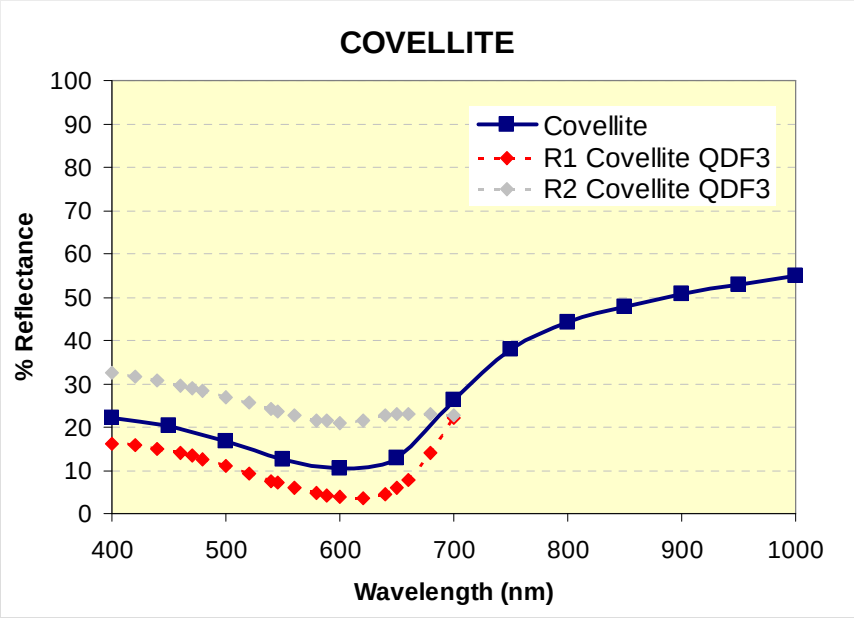
Mineral	Wavelength (nm)												
	400	450	500	550	600	650	700	750	800	850	900	950	1000
Gold	36.4	37.2	58.8										
Platinum	60.2	63.1	65.2										
Silver	81.7	87.6	90.5										
Arsenopyrite	51.2	51.7	52.7										
Bismuthinite	39.4	39.1	38.7										
Bornite	20.7	19.4	21.0										
Chalcopyrite	19.7	31.5	41.3										
Chalcocite	36.4	36.6	34.9										
Cinnabar	33.0	29.5	28.2										
Covellite	22.2	20.3	16.6										
Digenite	26.9	26.4	24.9										
Galena	50.3	46.9	44.4										
Marcasite	44.4	47.6	50.9										
Molybdenite	23.1	24.7	23.2										
Nickeline	42.8	41.5	44.9										
Pentlandite	32.2	38.3	42.6										
Pyrite	40.2	46.2	51.4										
Pyrrhotite	31.8	34.3	37.0	39.9	41.9	43.7	45.7	47.1	47.8	48.8	49.9	50.8	51.1



EXPERIMENTAL PROCESS

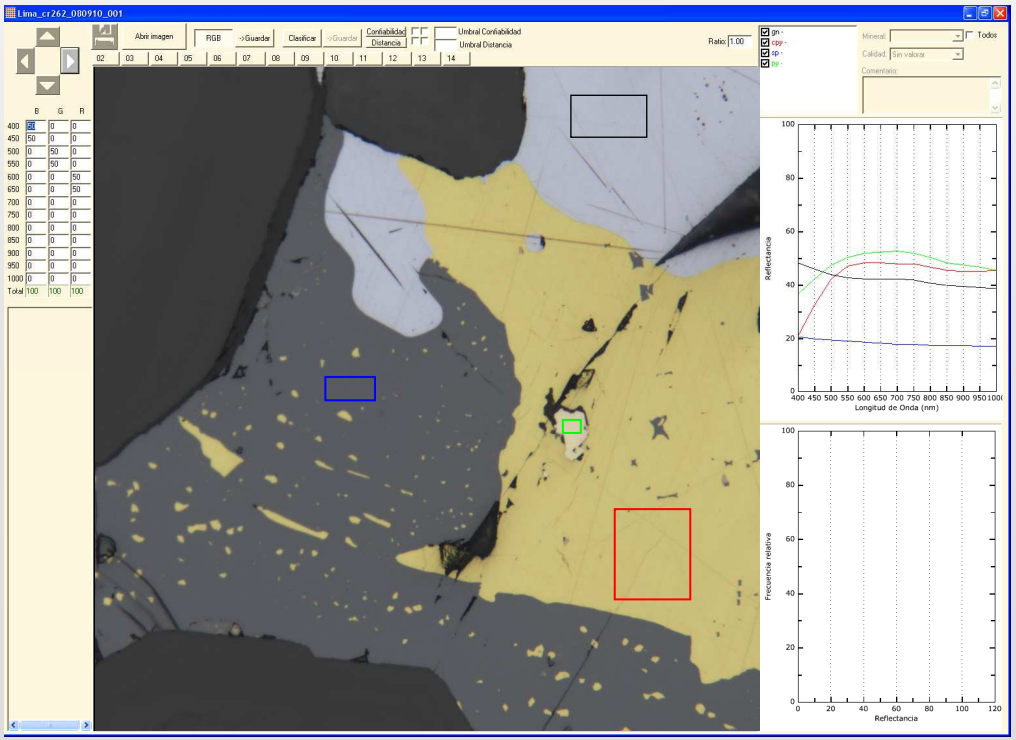
- **Data base construction**
  - **Includes ≈ 70 important ore minerals**
  - **Measures of ≈ 1100 ROI**
  - **Average spectrum *vs.* QDF3 data base**



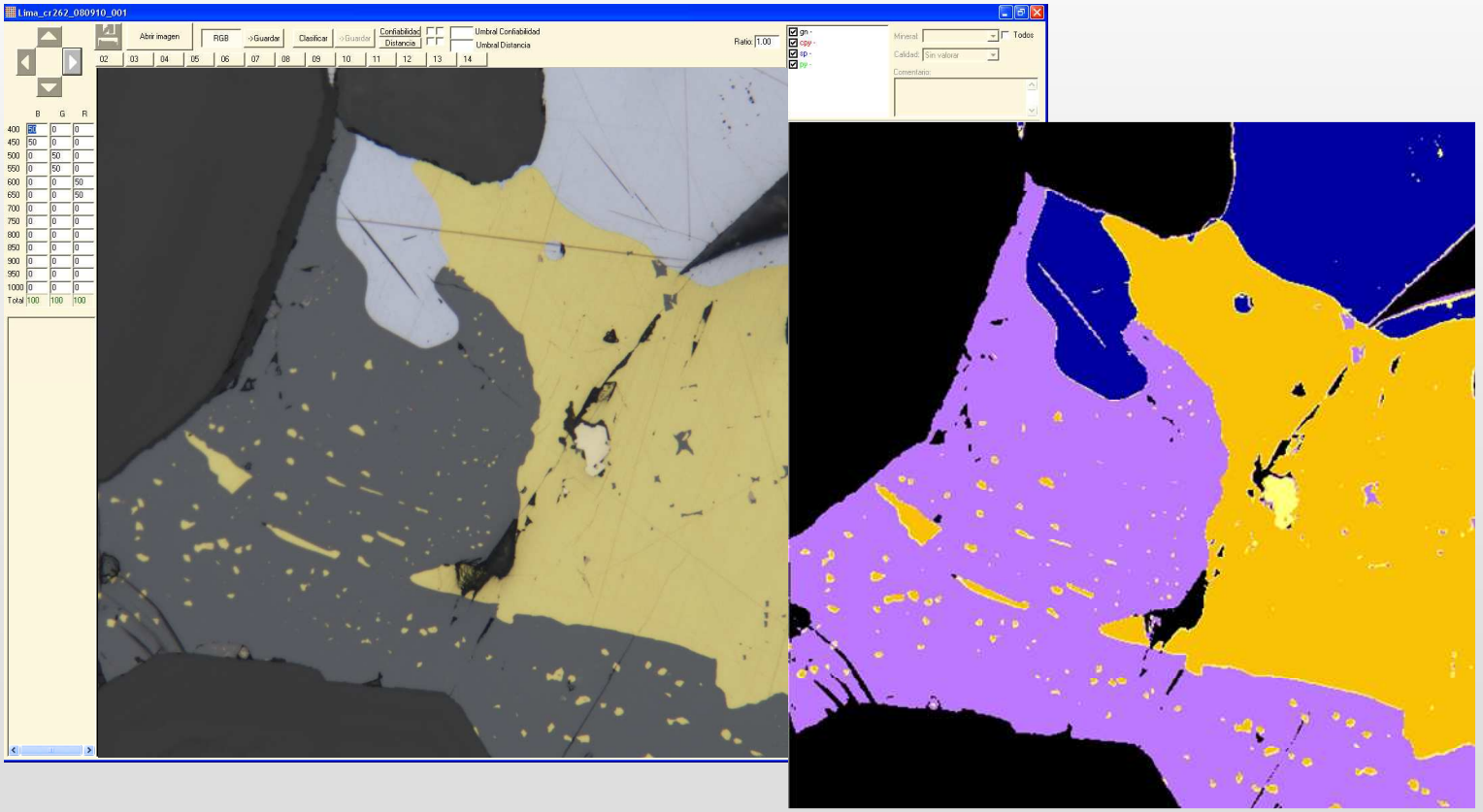


EXPERIMENTAL PROCESS

- **Mineral identification software: How does it work?**
  - The user selects areas to be analysed in the image
  - A data file is created containing average reflectance values for selected areas
  - The average reflectance values of selected areas are compared to the multispectral values in the data base
  - Identification of minerals is performed applying the **Minimum Mahalanobis distance** criteria

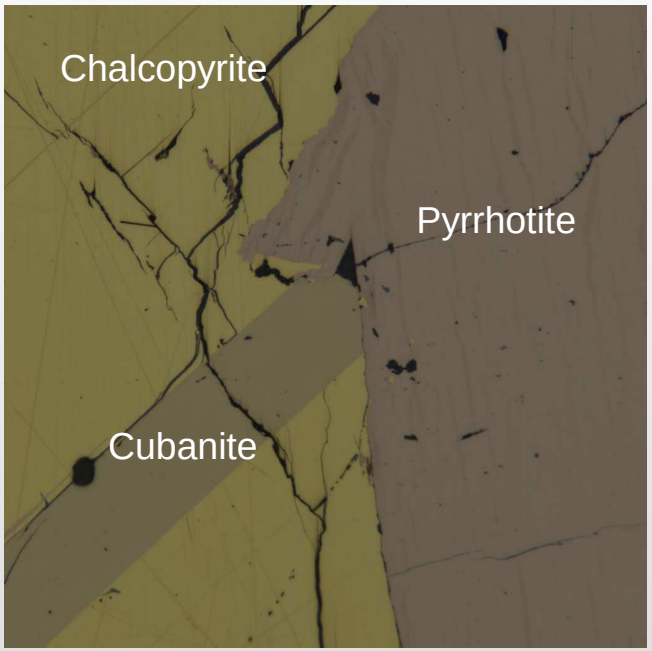


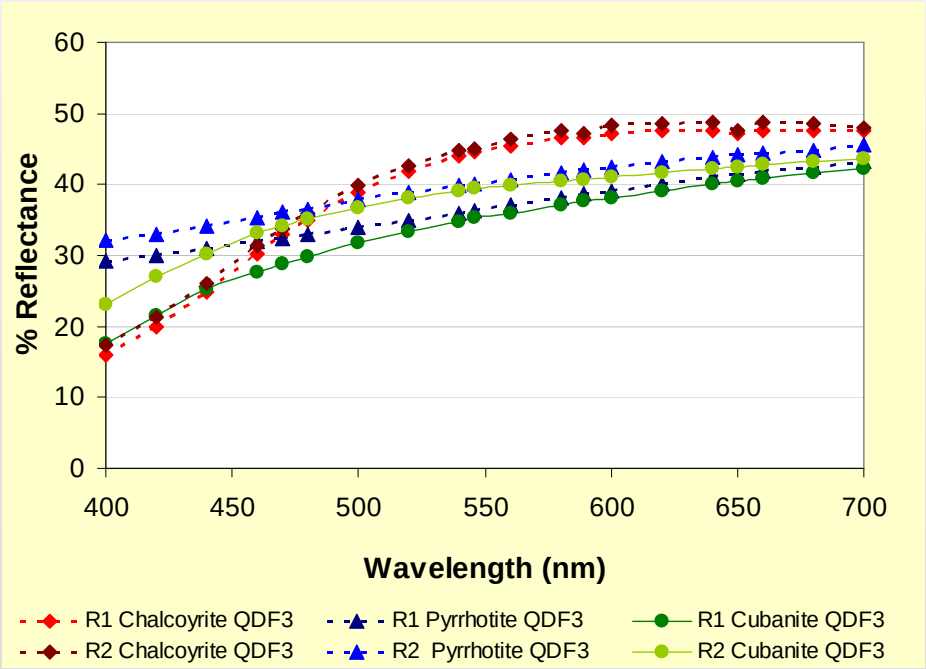
- **Image classification software**
  - **Using the Minimum Mahalanobis distance criteria every pixel in the image is classified**



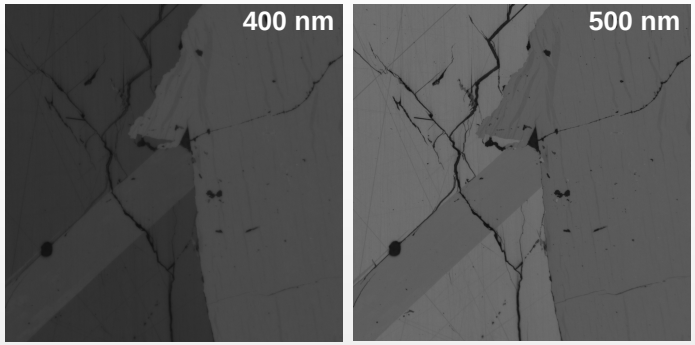
Results

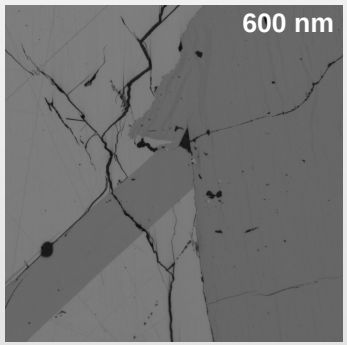
- **Enhanced discrimination of minerals using VNIR data**
  - **E.g. Discrimination between Chalcopyrite, Pyrrhotite and Cubanite difficult using just visible data**

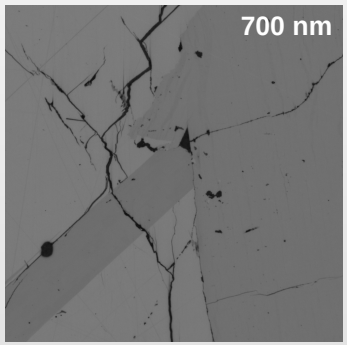


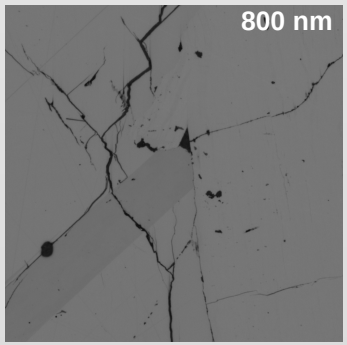


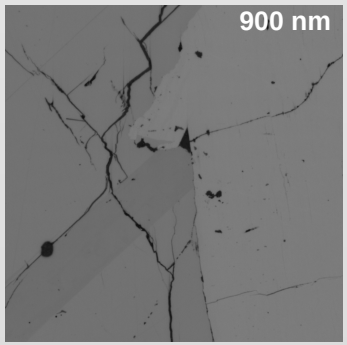
- **Enhanced discrimination of minerals using VNIR data**

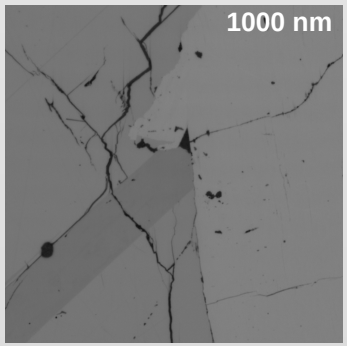


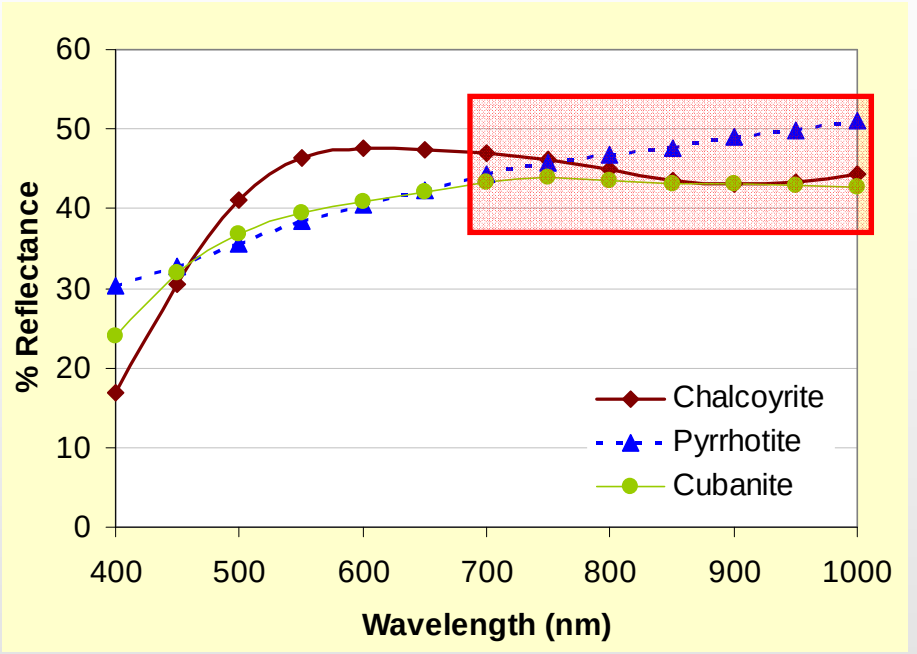








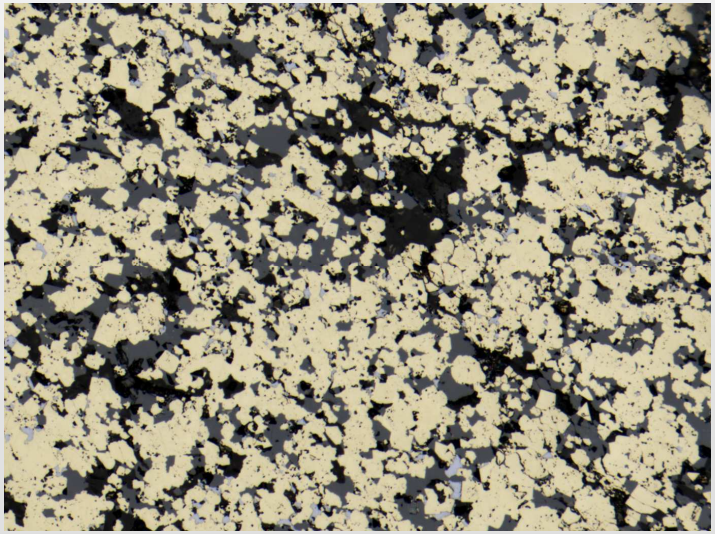


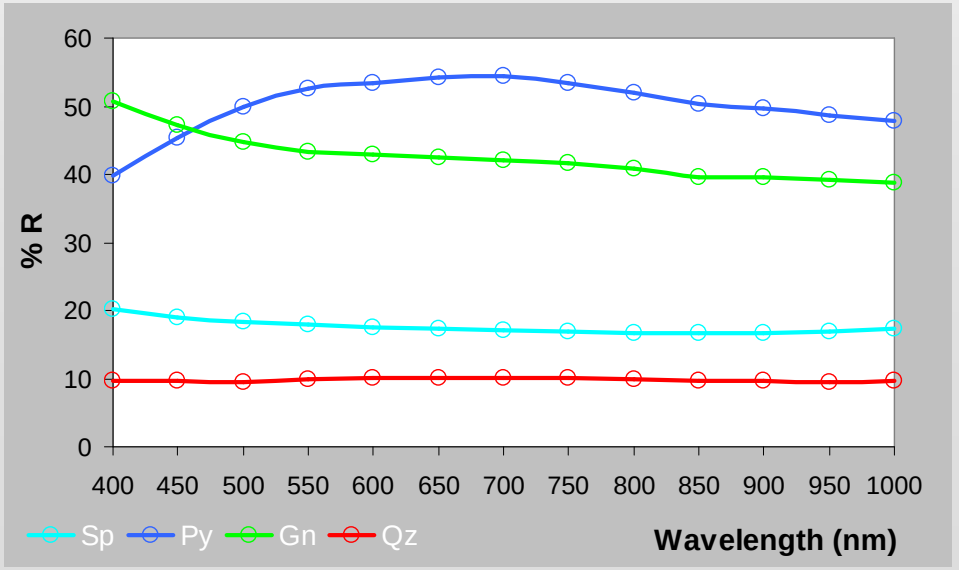


- **Quantitative Mineralogy**
  - **Reliable classified digital images allows for quantitative analysis**

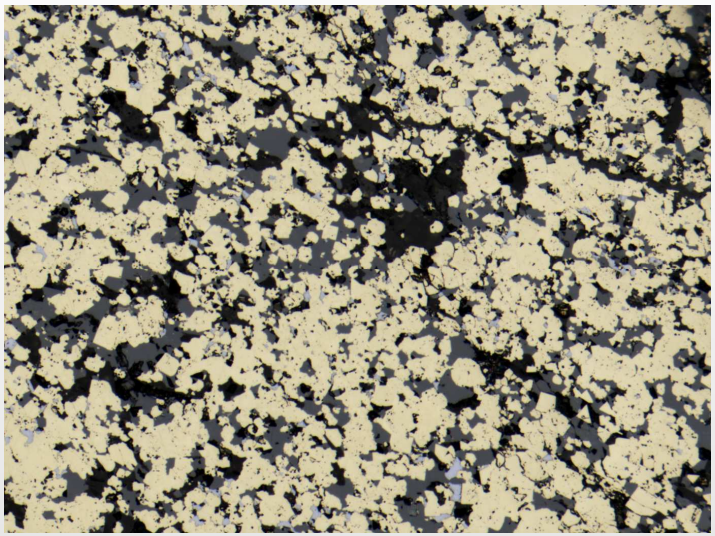
Case study: Sphalerite-Galena-Pyrite-Quartz aggregate

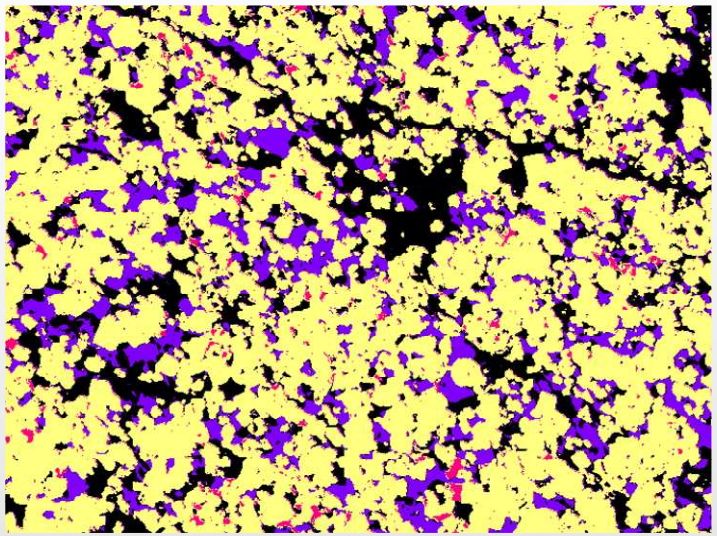
- **Modal analysis and grinding size determination in aggregates**



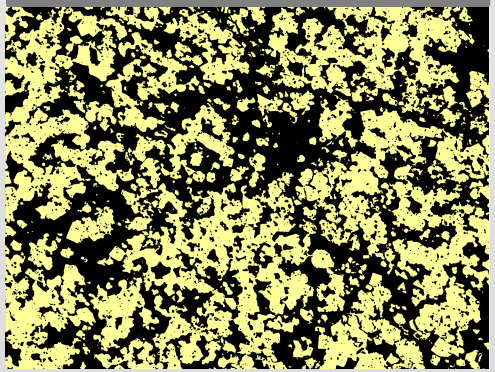


- **Quantitative Mineralogy**

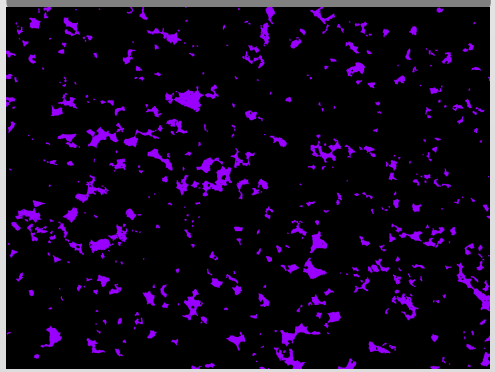




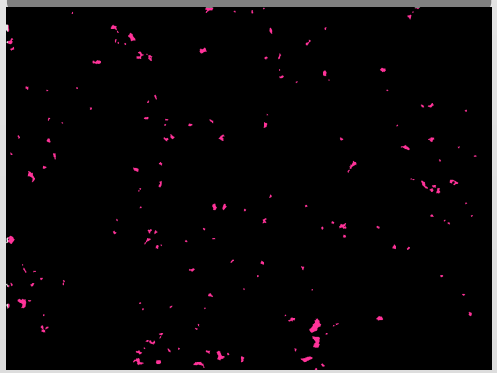
PYRITE



SPHALERITE



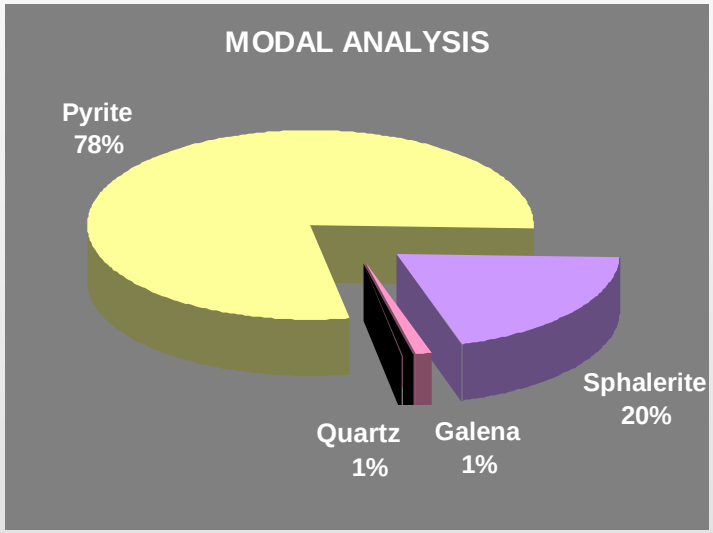
GALENA



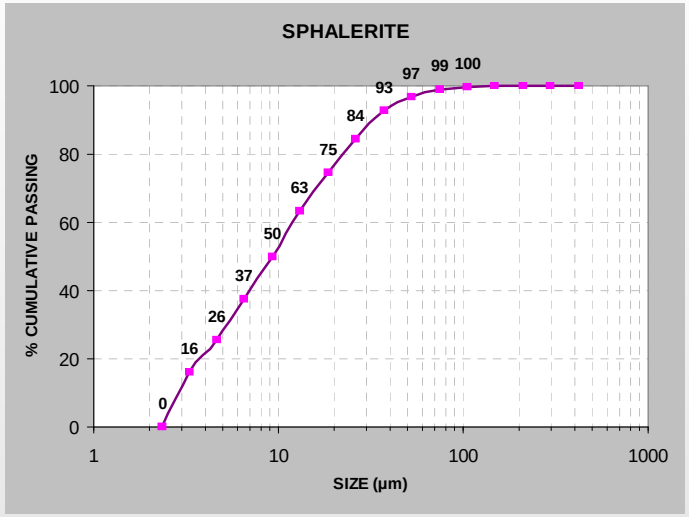
RESULTS

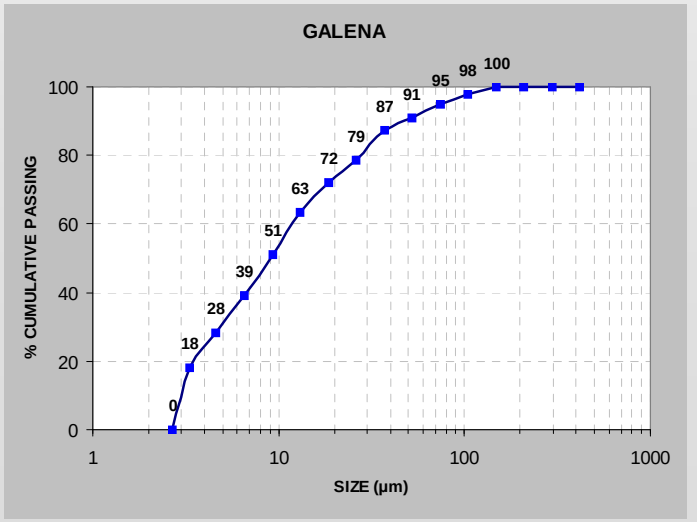
- **Quantitative Mineralogy**

  – **Modal Analysis**

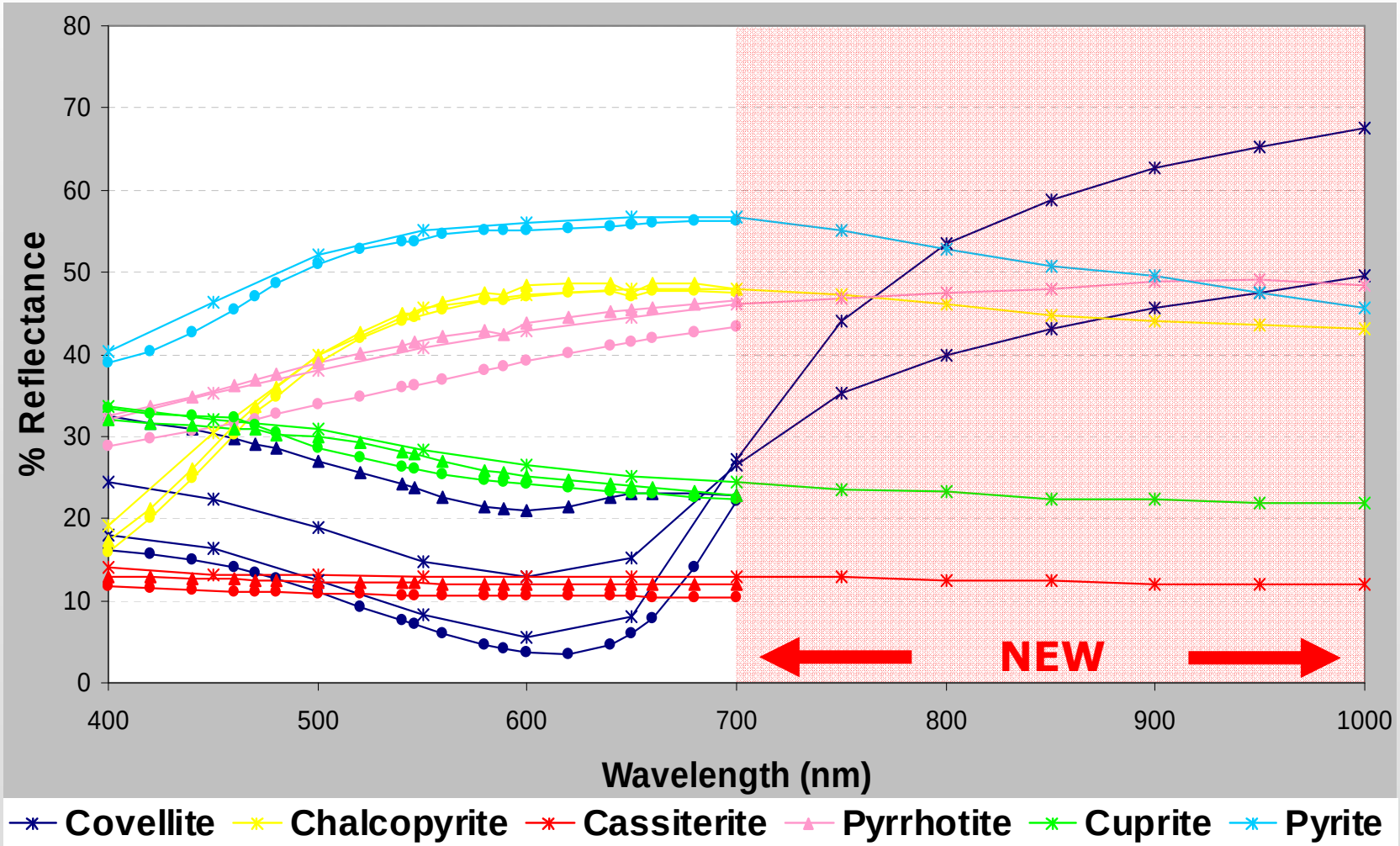


  – **Size distribution to predict grinding**





- **New VNIR data base for common minerals**



Conclusions

CONCLUSIONS

Automated ore characterisation using Reflected Light is possible

- **System requirements**
  - **Control on experimental conditions**
  - **Supervision by an expert**
  - **Possible additional criteria** (e.g. mineral associations)

- **Efficient help for ore identification & learning**
  - **The method provides support for basic ore microscopy / ore identification**

- **Efficient tool for Quantitative mineralogy / Geometallurgy**
  - **If image acquisition and image classification are secured**

CONCLUSIONS

ADVENTAGES

- Speed of operation
- Flexibility and versatility of operation mode
- Lower cost compare to SEM systems
- Higher performance compare to manual systems (i.e. Point Counter Device)

LIMITATIONS

- Discrimination between Gangue minerals and mounting media
  - Each single case, a particular solution
  - Ongoing work to find a general solution

POLITÉCNICA
"Ingeniamos el futuro"

Université de Liège

AUTOMATED CHARACTERISATION OF INTERGROWTH TEXTURES IN MINERAL PARTICLES

A CASE STUDY

Laura **PÉREZ-BARNUEVO**

Eric **PIRARD**

Ricardo **CASTROVIEJO**

SYPNOSIS

A new methodology is presented for the automated identification of intergrowth types and applied for the characterisation of chalcopyrite in the rougher concentrate of the Kansanshi Copper mine, Zambia.

- **Introduction**
  - TEXTURE in the context of MINERAL PROCESSING
- **Methodology**
- **Application. A case study**
  - Textural characterisation of Chalcopyrite in the rougher concentrate of the Kansanshi Copper mine.

Introduction

INTRODUCTION

What does TEXTURE mean in the context of MINERAL PROCESSING?

Textural features which determine possibilities of achieving or increasing mineral liberation and control mineral behaviour during concentration processes.

- **Grain size**
  How much grinding is required to achieve liberation?

- **Grain boundary irregularity**
  Will mineral grains break at the boundaries or not?

- **Intergrowth type**
  How mineral particles will behave during mineral processing?

What does TEXTURE mean in the context of MINERAL PROCESSING?

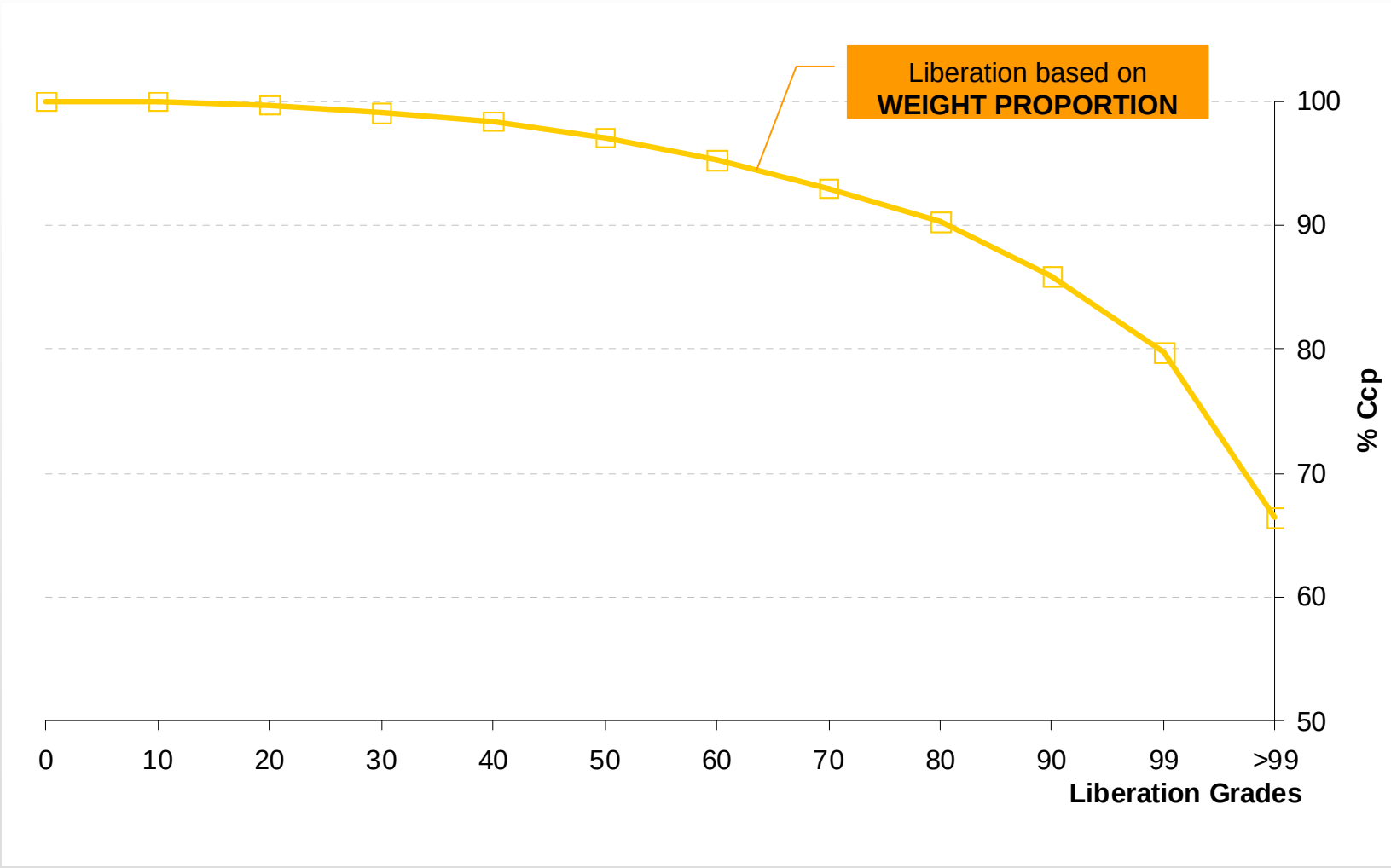
Textural features which determine possibilities of achieving or increasing mineral liberation and control mineral behaviour during concentration processes.

- Grain size
- How much grinding is required to achieve liberation?

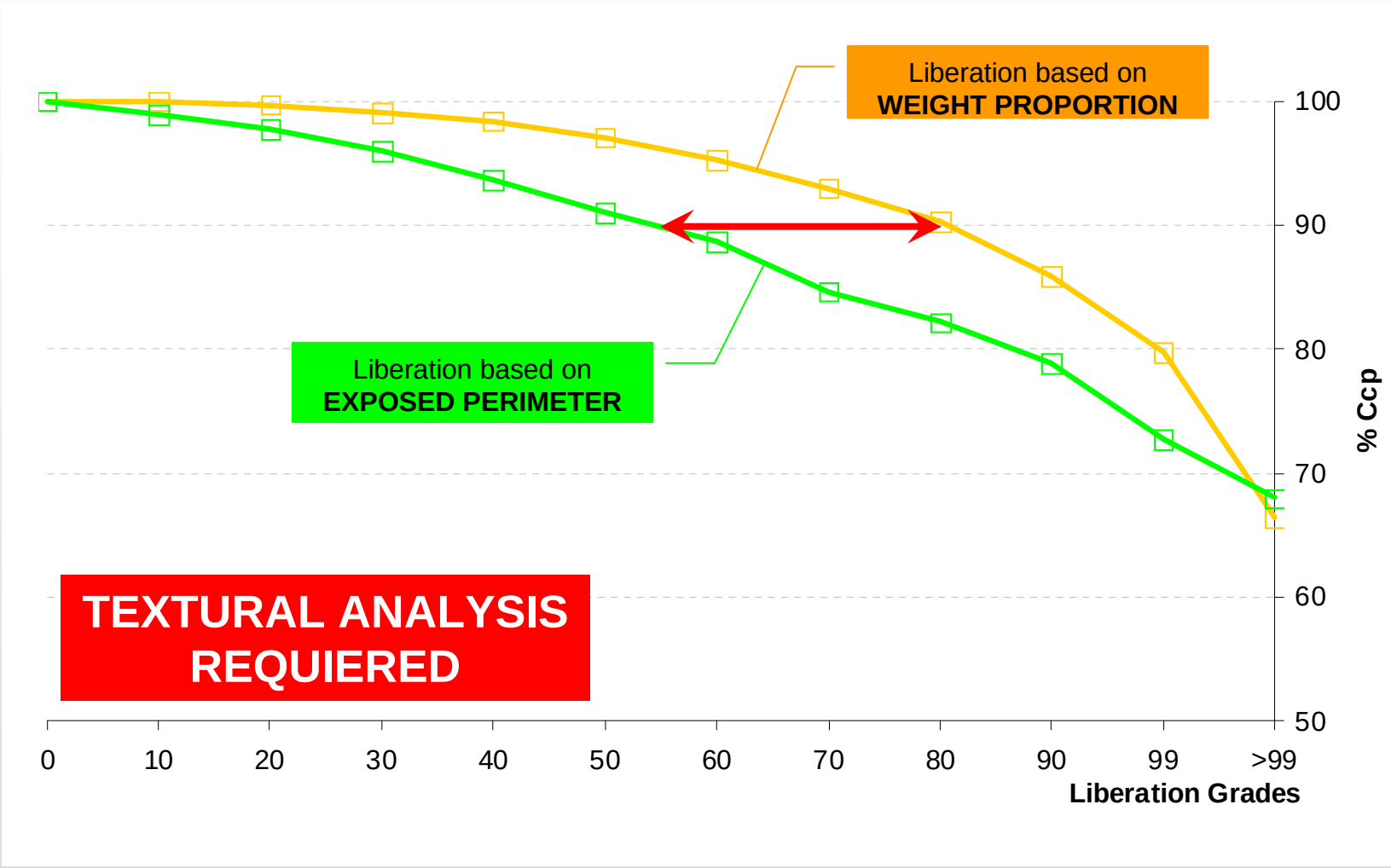
- Grain boundary irregularity
- Would mineral grains break at the boundaries or not?

- **Intergrowth type**
- **How mineral particles will behave during mineral processing?**

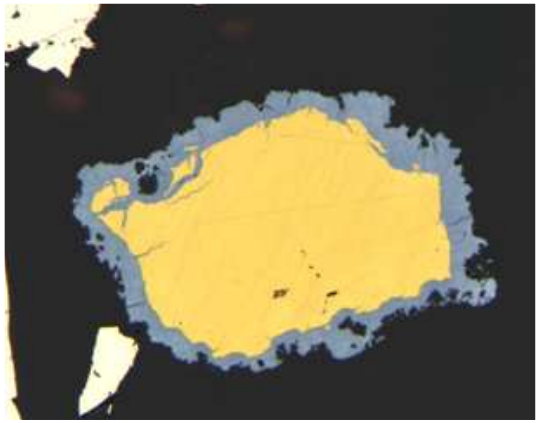
INTRODUCTION

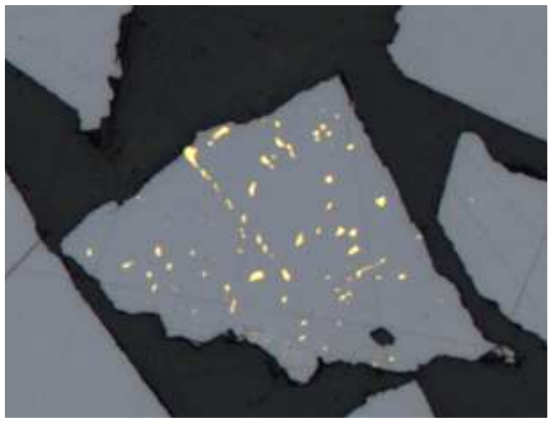


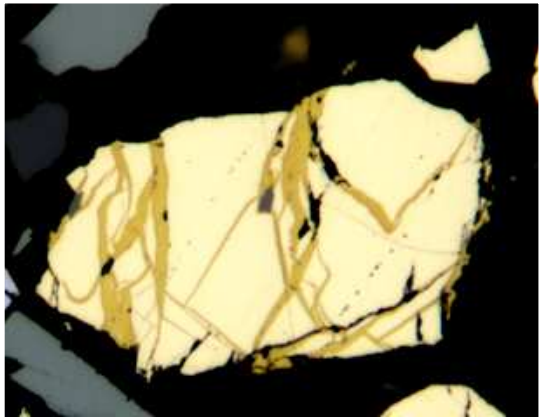
INTRODUCTION

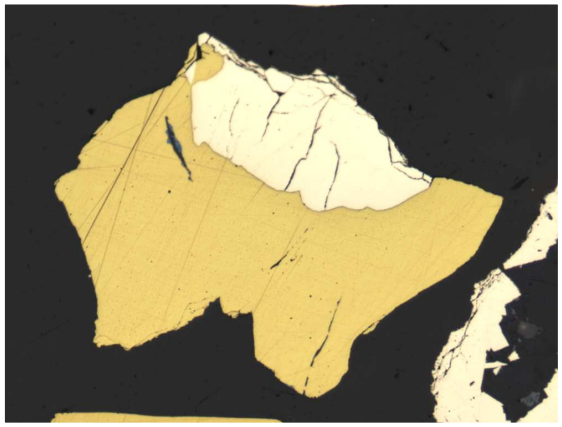


RELEVANT INTERGROWTH TYPES









Methodology

METHODOLOGY

DIGITAL IMAGE

LINEAR INTERCEPTS METHOD

STEREOLOGY

GEOMETRIC AND STEREOLOGICAL PARAMETERS

MINERALLURGICAL INDICES

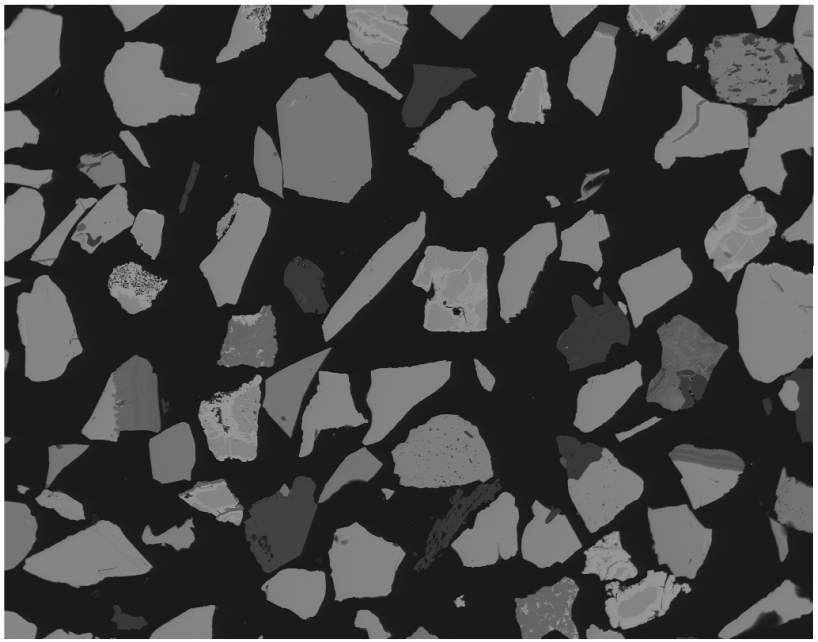
DISCRIMINANT ANALYSIS

INTERGROWTH TYPE IDENTIFICATION

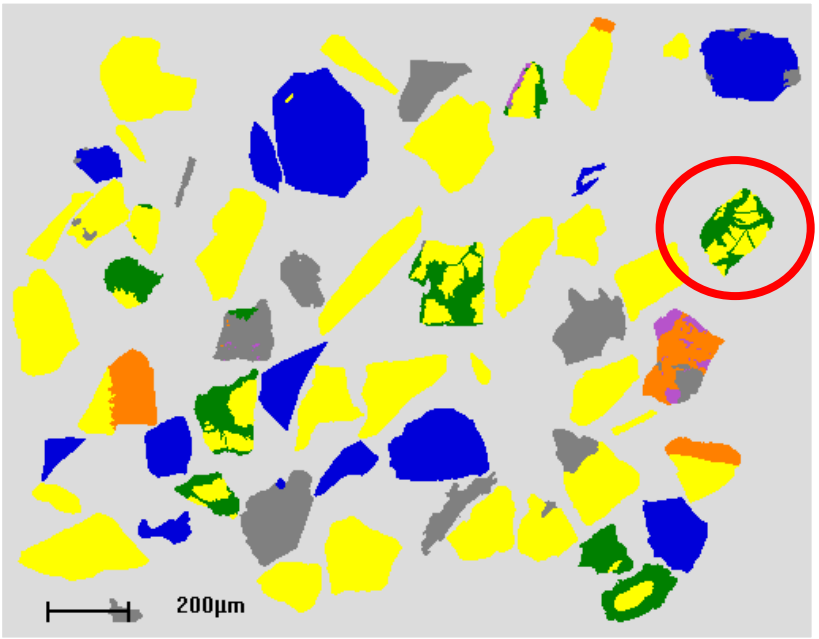
COMPLETE MINERALOGICAL CHARACTERISATION

METHODOLOGY

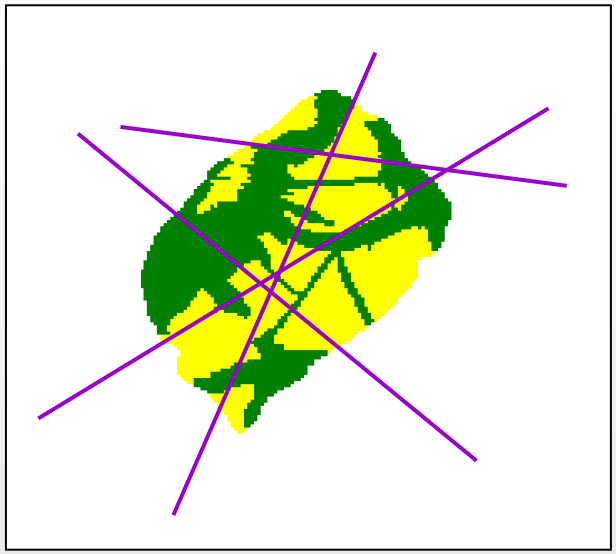
DIGITAL IMAGE



CLASSIFIED IMAGE



METHODOLOGY



LINEAR INTERCEPTS METHOD

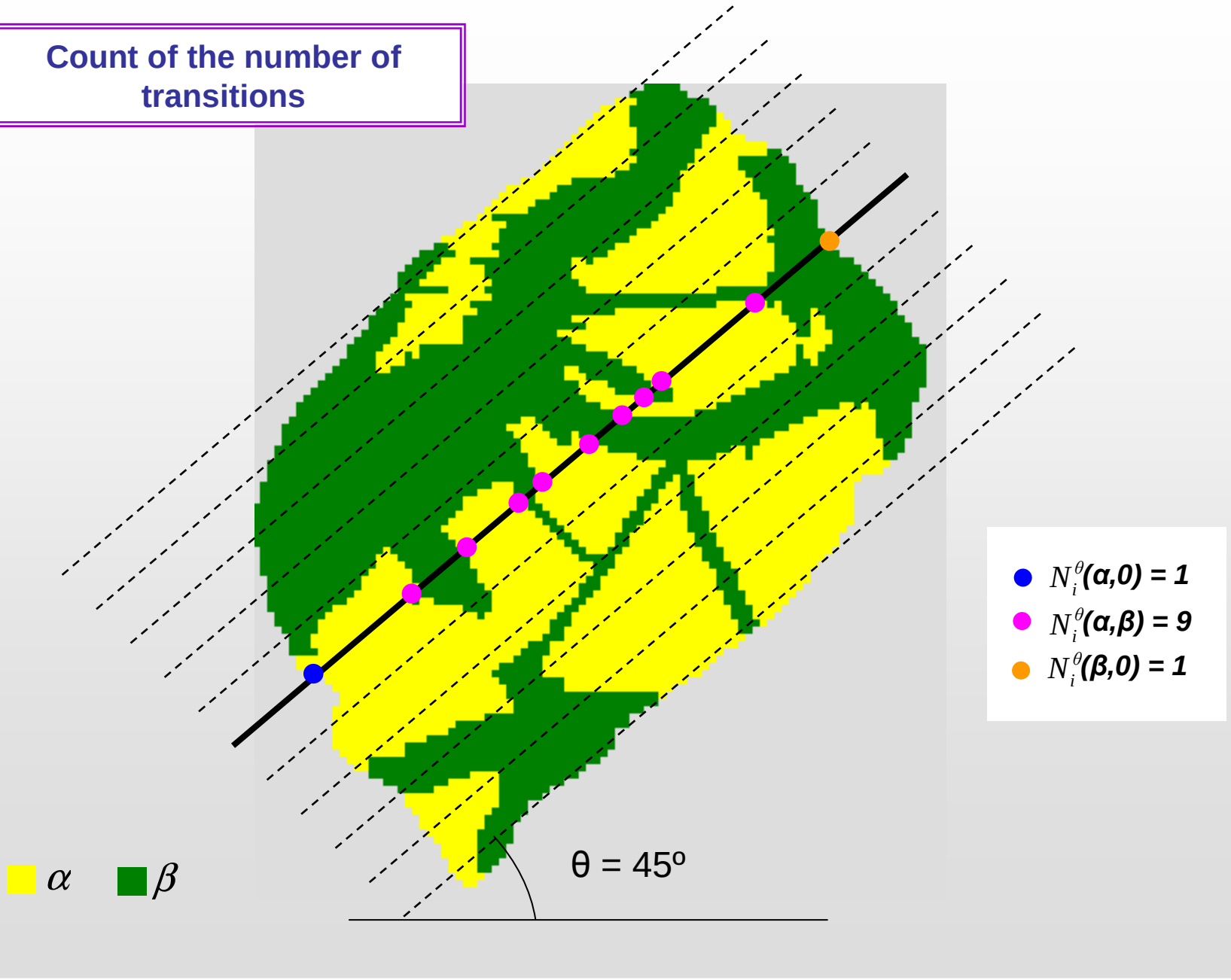
Multiple lines are drawn on each particle in different orientations to measure:

- Number of transitions between phases and between phases and background along a test line

- Length of test line on each phase

METHODOLOGY

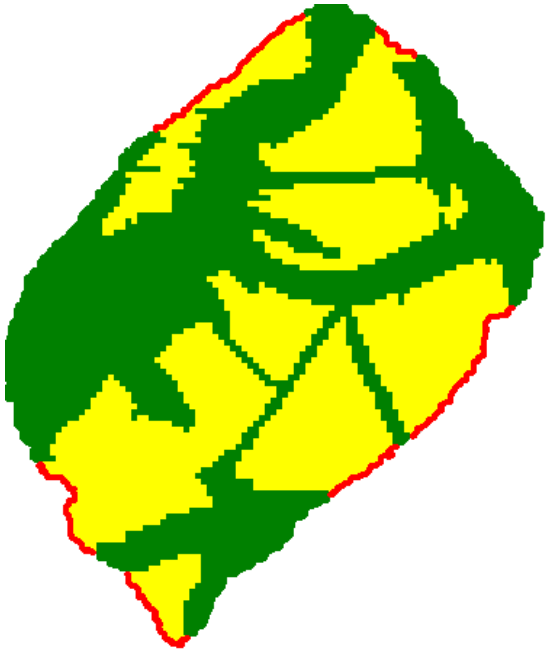
Count of the number of transitions



PARAMETERS BASED ON TRANSITIONS COUNTS

EXPOSED PERIMETER

$$B(\alpha,0) = \frac{\pi d}{2} \times \overline{\sum_{\theta} \sum_{i} N_i^{\theta}(\alpha,0)}$$



α
β

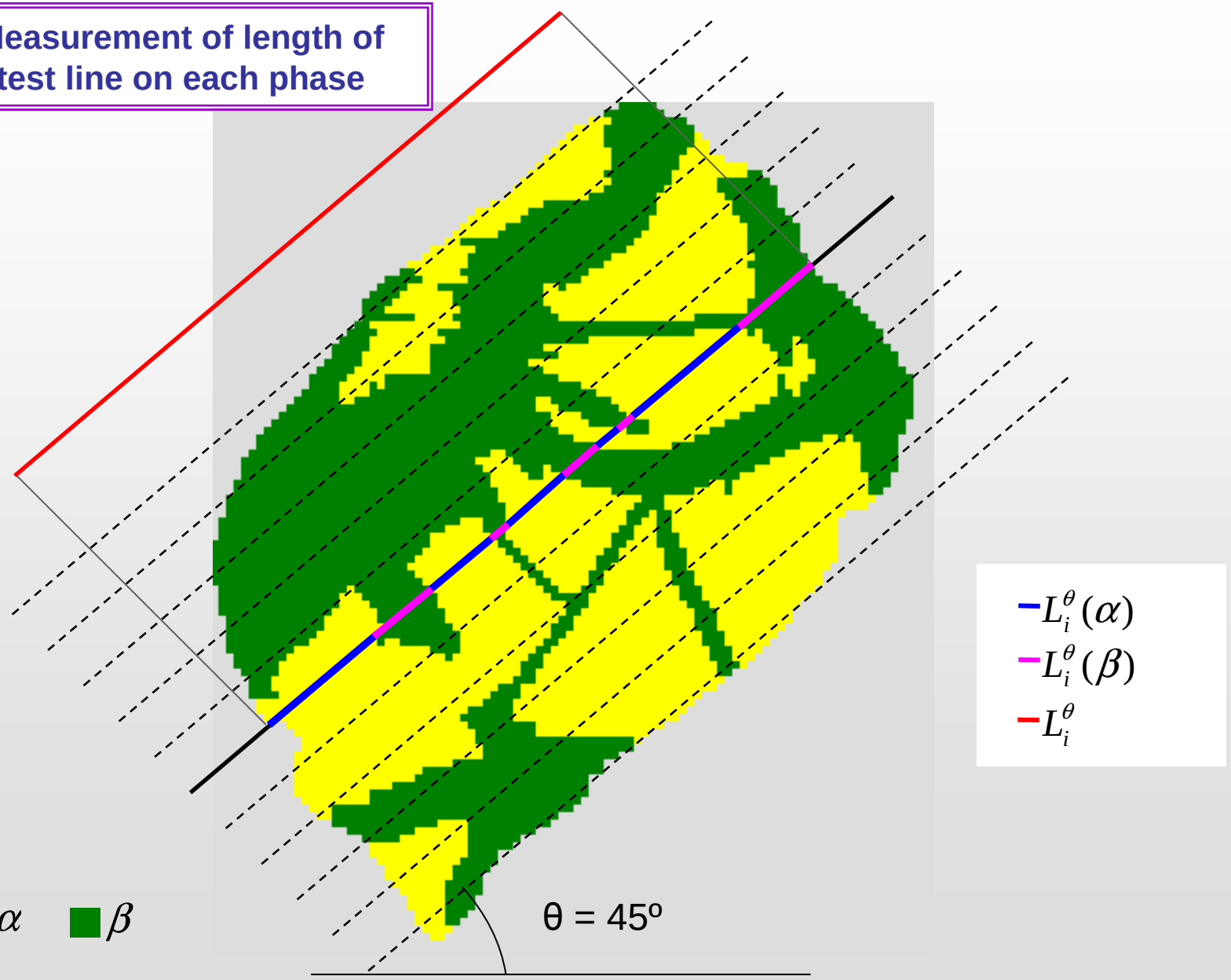
SURFACE AREA PER UNIT VOLUME

$$S_V(\alpha\beta) = 2 \times \frac{\overline{\sum_{\theta} \sum_{i} N_i^{\theta}(\alpha\beta)}}{\sum_{i} L_i^{\theta}}$$

α
β

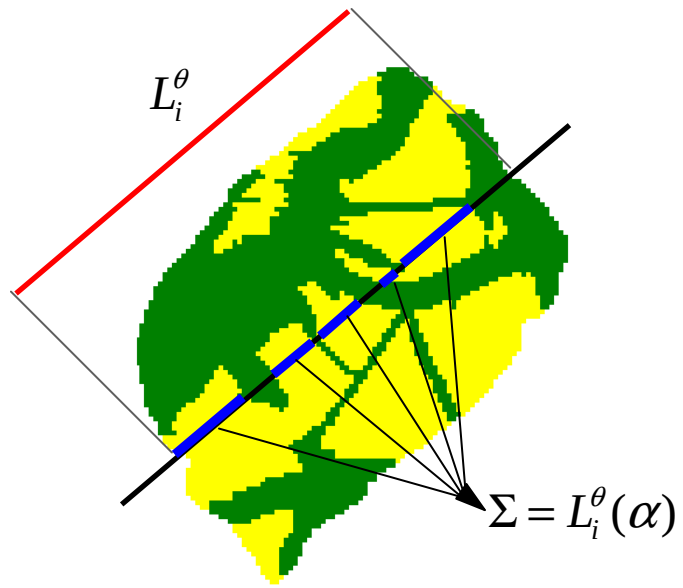
METHODOLOGY

Measurement of length of test line on each phase



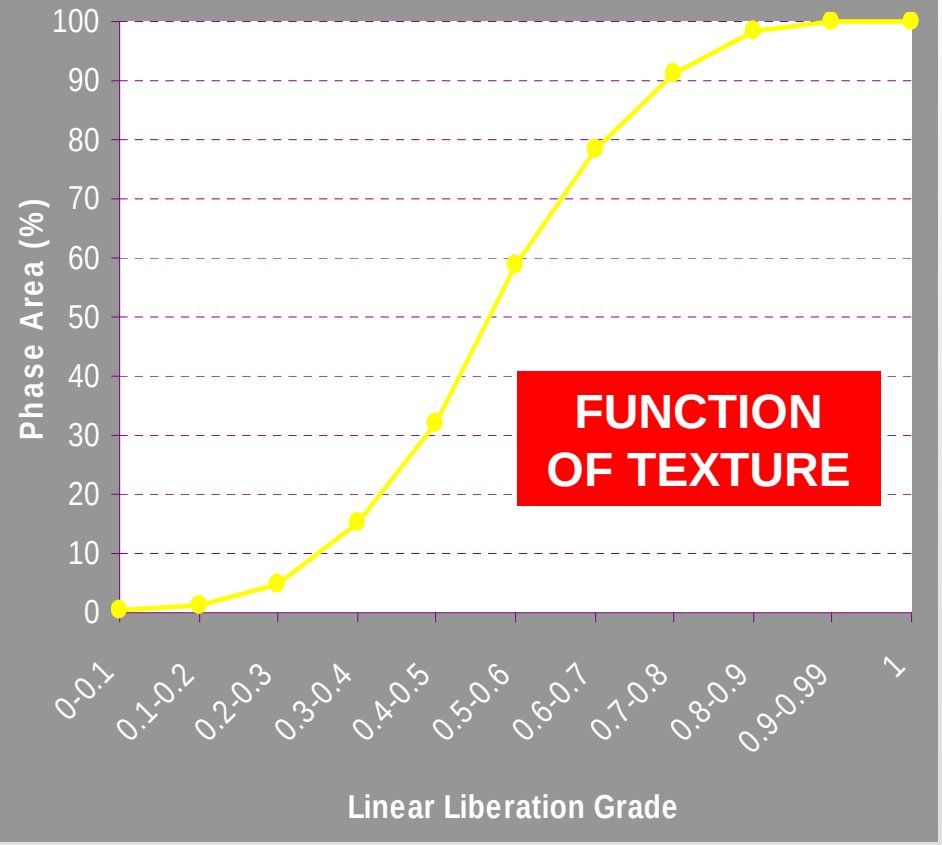
PARAMETERS BASED ON LINEAR GRADE COMPUTATION

LINEAR GRADE



$$L_{Li}^{\ \theta}(\alpha) = \frac{L_i^\theta(\alpha)}{L_i^\theta}$$

LINEAR GRADES DISTRIBUTION



METHODOLOGY

MINERALLURGICAL INDICES

INDEX	DEFINITION	SIGNIFICANCE
CLASSICAL LIBERATION INDICES		
$A_A(\alpha)$	Volumetric proportion	Proportion of phase α in the particle
$B_B(\alpha)$	Surface Liberation	Proportion of phase α exposed in the particle
TEXTURE COMPLEXITY INDEX		
$I_{TC}(\alpha\beta)$	Texture complexity Index	Grain boundary irregularity and texture complexity quantifier
LINEAR GRADE INDICES		
$F_{LL}(\alpha)$	Liberated Linear Fraction	Proportion of α in the particle in liberated linear intercepts
$F_{ML}(\alpha)$	Mixed Linear Fraction	Proportion of α in the particle in unliberated linear intercepts
$L_{L1}(\alpha)$	Linear grades distribution shape quantifier	The shape of the linear grades distribution is a function of texture.
PHASE CONTACT INDICES PROPOSED BY OTHER AUTHORS		
$I_{A\text{-}G}(\alpha\beta)$	Intergrowth Index	Surface quantifier of αβ intergrowth
$I_J(\alpha\beta)$	Jeulin coordination Index	Probability of the αβ contact in a multiphase system
$I_{CG}(\alpha\beta)$	Contiguity Index	Proportion of α intergrown with β

METHODOLOGY

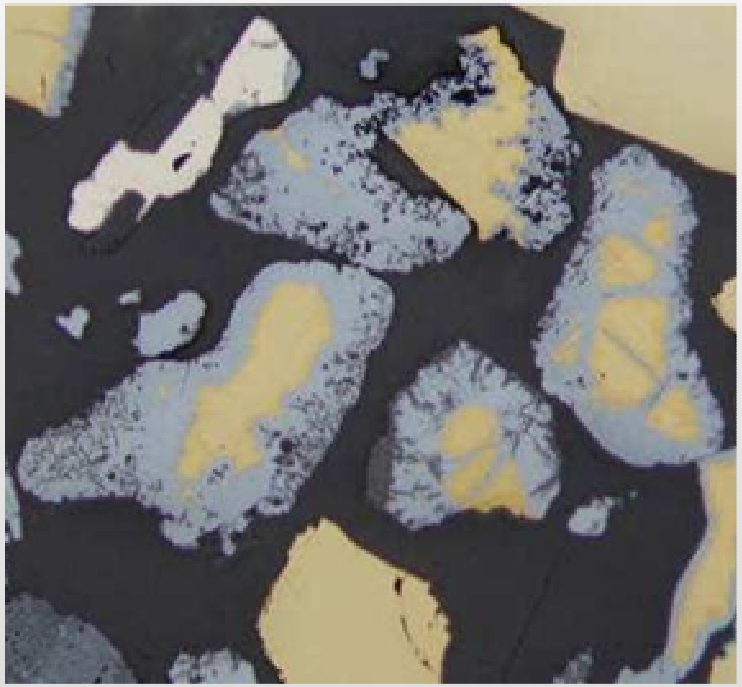
	Modal Composition (%)						Surface Liberation (%)	Intergrowth Type	Grain Size (µm)		I_{TC}
	Ccp	SsCu	Hem	SFe	CuOx	Gg					
	30.2	0.0	69.8	0.0	0.0	0.0	40.0	Simple	Chalcopyrite Other phases	89 163	1.62
	16.7	83.3	0.0	0.0	0.0	0.0	20.0	Simple	Chalcopyrite Other phases	49.9 116	1.69
	39.0	100.0	0.0	0.0	0.0	0.0	25.0	Simple	Chalcopyrite Other phases	62 58	2.30
	46.4	53.6	0.0	0.0	0.0	0.0	27.0	Stockwork Matrix	Chalcopyrite Other phases	73.7 89.2	2.81
	50.8	49.2	0.0	0.0	0.0	0.0	40.0	Stockwork Matrix	Chalcopyrite Other phases	62 62	3.86
	60.9	26.4	0.0	0.0	11.5	0.0	19.0	Inclusion coated by a rim	Chalcopyrite Other phases	78 34.9	1.84
	74.4	0.0	0.0	0.0	0.0	25.6	67.0	Simple	Chalcopyrite Other phases	174.6 104.8	1.18
	91.7	0.0	8.3	0.0	0.0	0.0	82.0	Simple	Chalcopyrite Other phases	155.2 48.3	1.14
	24.7	75.3	0.0	0.0	0.0	0.0	0.0	Inclusion coated by a rim	Inclusion Rim Thickness	73 37	2.21
	60.0	0.0	40.0	0.0	0.0	0.0	53.0	Simple	Chalcopyrite Other phases	128 85.4	1.05
	49.2	50.8	0.0	0.0	0.0	0.0	42.0	Stockwork Matrix	Chalcopyrite Other phases	46.6 53.2	4.97

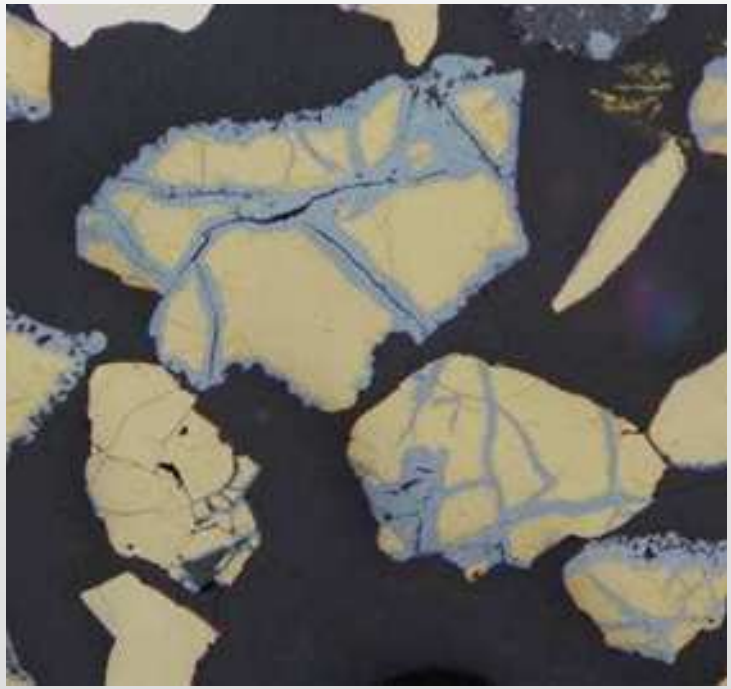
Application

Intergrowth type characterisation of chalcopyrite in the Kansanshi rougher concentrate.

APPLICATION

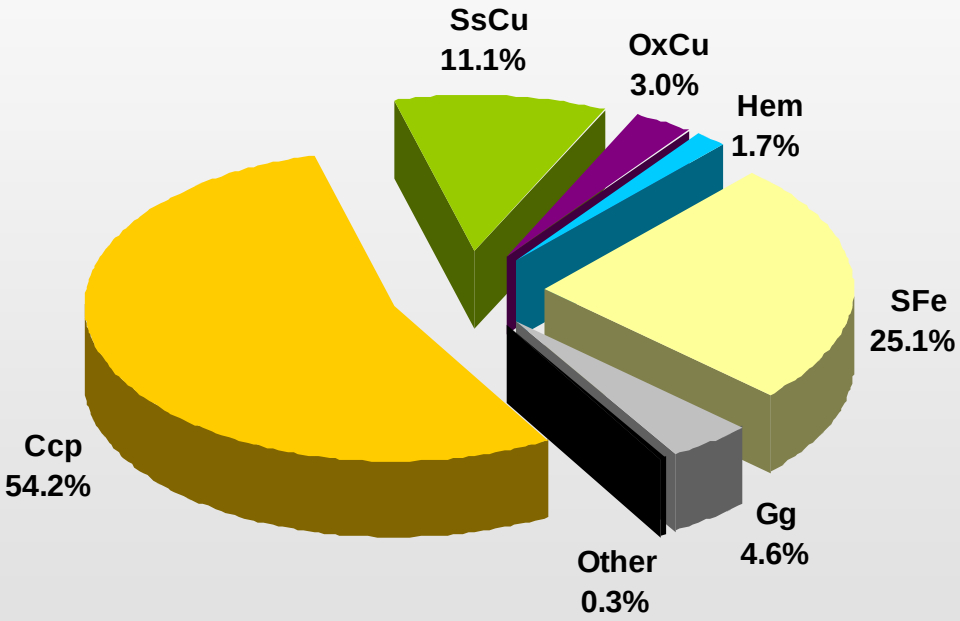
- Rougher Concentrate (>150 µm)
  - Presents good examples of complex copper mineralogy





APPLICATION

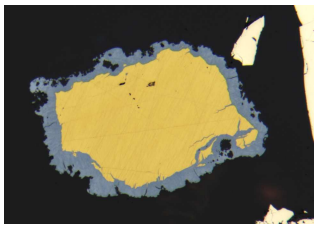
- Rougher Concentrate (>150 µm)
  - Modal Analysis



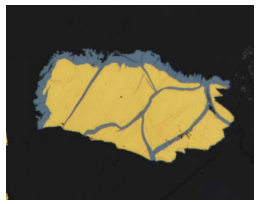
- **Ccp**: chalcopyrite
- **SsCu**: Secondary Copper Sulfides (bornite, chalcocite, covellite, digenite).
- **OxCu**: Copper oxides (malachite, chrysocolle)
- **Hem**: hematites
- **SFe**: iron Sulfides (pyrite, pyrrothite)
- **Gg**: gangue (quartz, clacite, dolomite, albite, mica, rutile)
- **Other**

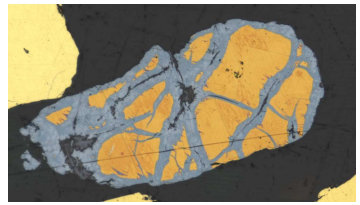
How many chalcopyrite is in the form of…

inclusion coated by a rim or a semi-rim?

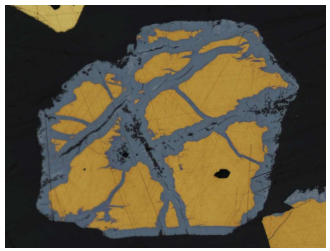


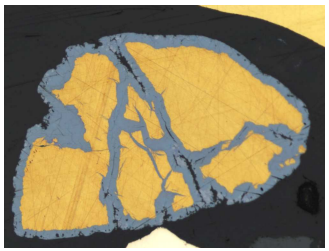
matrix crossed by “stockwork”?



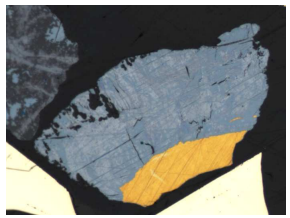


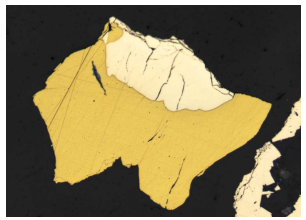
matrix crossed by “stockwork” and coated by a rim?



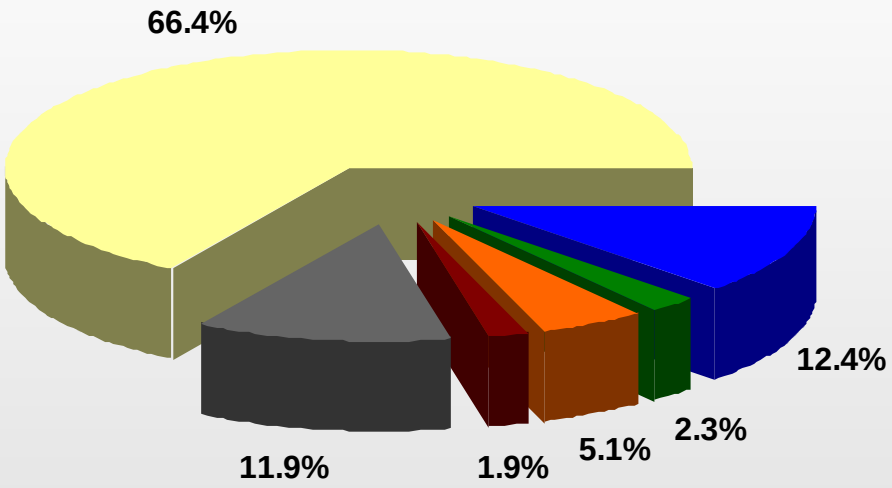


simple intergrowth?

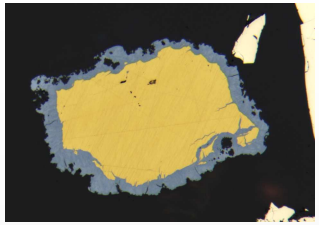




Chalcopyrite distribution by intergrowth type



APPLICATION



- Which is the composition of the rim?
- Which is the thickness of the rim?
- Which is the grain size of the inclusion?

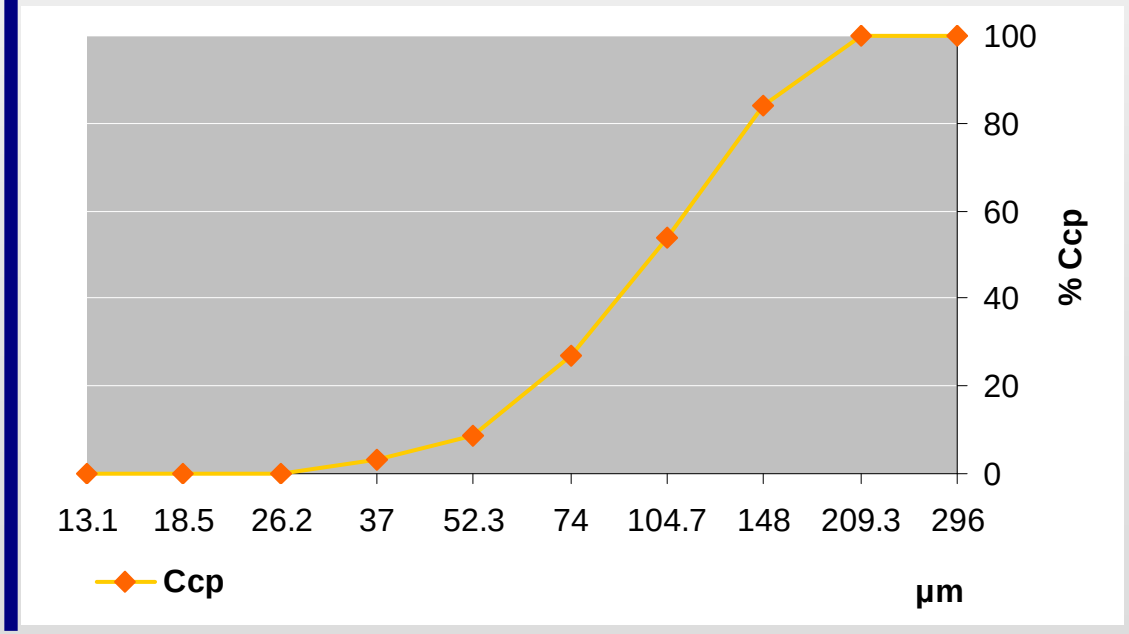
RIM COMPOSITION

		RIM COMPOSITION	% Ccp
BINARY	1.8	SsCu	1.8
		SFe	0.0
		CuOx	0.0
		Hem	0.0
		Gg	0.0
		Other	0.0
TERNARY	0.3	SsCu-SFe	0.0
		SsCu-CuOx	0.0
		SsCu-Hem	0.0
		SsCu-Gg	0.1
		SsCu-Other	0.1
		SFe-CuOx	0.0
		SFe-Hem	0.0
		SFe-Gg	0.0
		SFe-Other	0.0
		CuOx-Hem	0.0
		CuOx-Gg	0.0
		CuOx-Other	0.0
		Hem-Gg	0.0
		Hem-Other	0.0
		Gg-Other	0.0
		More than 3 phases	0.3
		TOTAL	2.3

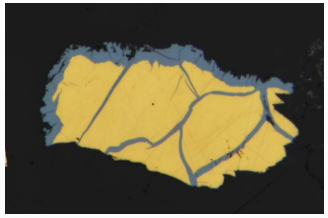
RIM TICKNESS (µm)

AVERAGE	MIN.
33.7	7.5

Ccp INCLUSION GRAIN SIZE



APPLICATION

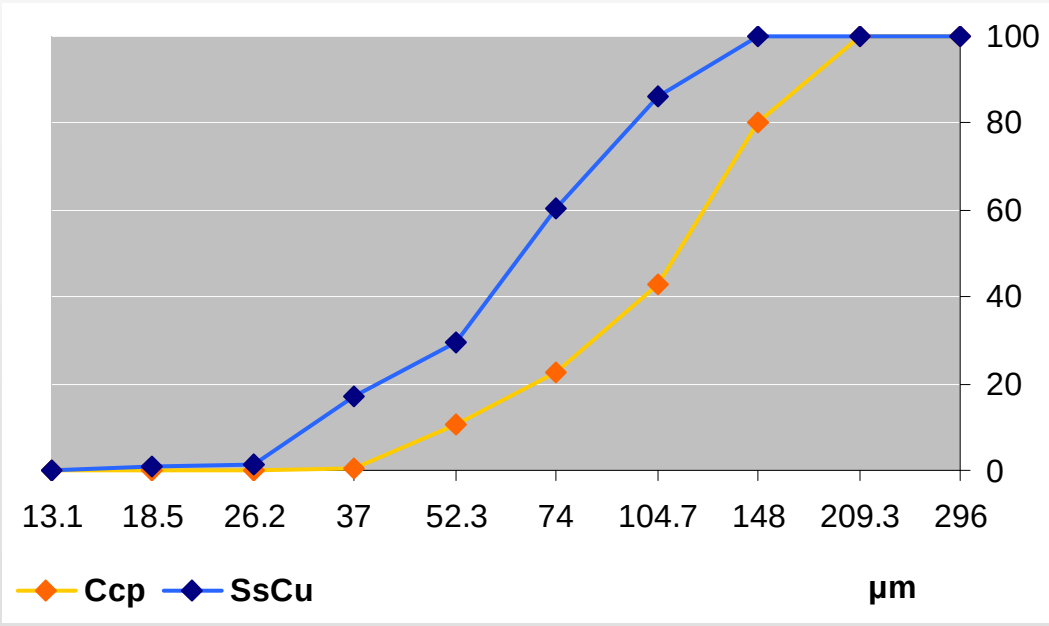


- Which is the composition of the stockwork?
- Which is the grain size of the matrix?
- Which is the grain size of the stockwork?

STOCKWORK COMPOSITION

		STOCKWORK COMPOSITION	% Ccp
BINARY	3.7	SsCu	3.7
		SFe	0.0
		CuOx	0.0
		Hem	0.0
		Gg	0.0
		Other	0.0
TERNARY	0.5	SsCu-SFe	0.1
		SsCu-CuOx	0.0
		SsCu-Hem	0.0
		SsCu-Gg	0.0
		SsCu-Other	0.4
		SFe-CuOx	0.0
		SFe-Hem	0.0
		SFe-Gg	0.0
		SFe-Other	0.0
		CuOx-Hem	0.0
		CuOx-Gg	0.0
		CuOx-Other	0.0
		Hem-Gg	0.0
		Hem-Other	0.0
		Gg-Other	0.0
		More than 3 phases	0.9
		TOTAL	5.1

GRAIN SIZE DISTRIBUTION



CONCLUSIONS

When complex texture exists, information given by liberation curves has to be complemented with textural analysis

- **Indices developed are suitable for the characterisation of texture within mineral particles**
  - Each index provides information to characterise a particular mineralogical feature
  - Their ability to be used as discriminant variables in the identification of the intergrowth type
- **Information provided by the method enables a very detailed characterisation of mineral particles**
- **In the future…**

  Explore the PREDICTIVE capacity of some minerallurgical indices

THANK YOU!